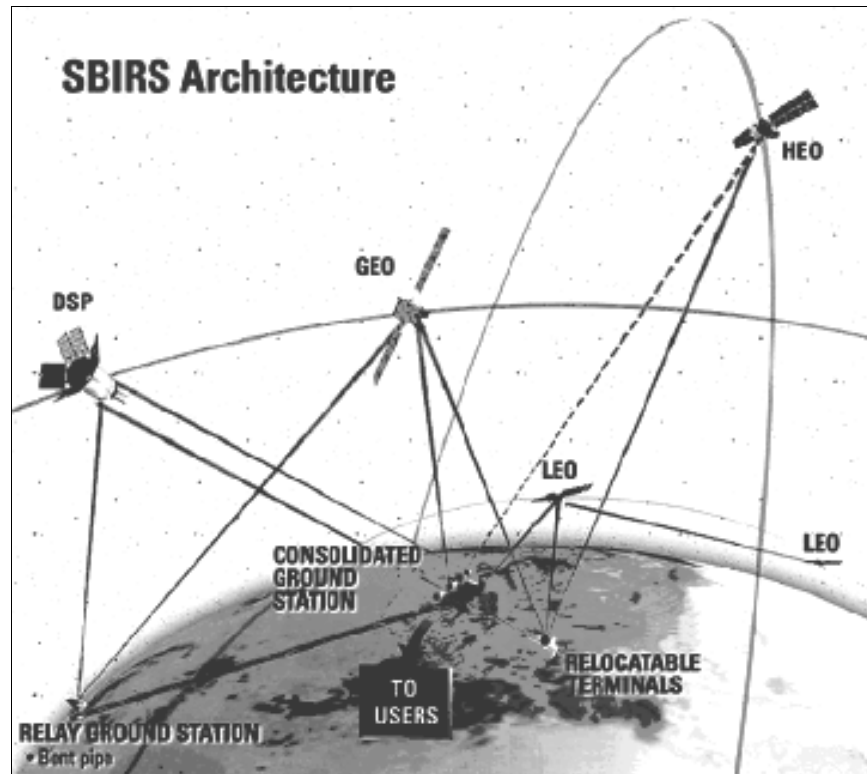


## SPACE-BASED INFRARED SYSTEM (SBIRS)



### DoD ACAT ID Program

|                            |   |
|----------------------------|---|
| Total Number of Systems:   | 30+ (TBD) satellites<br>(GEO, HEO and LEO orbits)             |
| Total Program Cost (TY\$): | \$7613M (excludes low component)                              |
| Average Unit Cost (TY\$):  | Varies by component   |
| First satellites:          | FY02 (HEO delivery)<br>FY04 (GEO launch)<br>FY06 (LEO launch) |

### Prime Contractor

Lockheed Martin (High);  
TRW/Raytheon and Spectrum  
Astro/Northrop Grumman  
(Low PDRR)

### SYSTEM DESCRIPTION & CONTRIBUTION TO JOINT VISION 2010

The Space-Based Infrared System (SBIRS) responds to the increasing need of U.S. military forces for accurate and timely warning of ballistic missile attack. SBIRS will replace the current Defense Support Program (DSP), and is designed to meet U.S. infrared space-based surveillance and warning needs through the next two to three decades. SBIRS improves support to theater Commander-in-Chiefs, U.S. deployed forces and allies by providing detailed information in four mission areas: Missile Warning, Missile Defense, Technical Intelligence and Battlespace Characterization.

By increasing the quality and timeliness of missile warning data over that provided by the DSP, SBIRS enhances *information superiority* and supports the operational concepts of *full-dimensional protection* and *precision engagement* by providing data directly to theater commanders in a timely and survivable manner, thus enabling U.S. forces to immediately react to a threat.

The SBIRS space segment includes a High and a Low component. The High component comprises six satellites: four in Geosynchronous (GEO) earth orbit, with first launch in FY04, and two hosted payloads in Highly Elliptical Orbit (HEO). A fifth GEO satellite will be procured as a replenishment/spare. The Low component includes approximately 24 Low Earth Orbit (LEO) satellites, with first launch in FY06. SBIRS High will meet and improve on current DSP operational requirements for missile warning, technical intelligence and battlespace characterization, and will meet a sub-set of requirements related to missile defense. SBIRS Low will provide a unique, precision, mid-course tracking capability and provide discrimination data critical for effective ballistic-missile defense, as well as an enhanced capability to support other SBIRS missions.

The SBIRS ground segment is being acquired in three increments, and includes a Continental U.S. (CONUS)-based Mission Control Station, a Mission Control Station Backup, a Survivable Mission Control Station, overseas Relay Ground Stations, Multi-Mission Mobile Processors, and associated communications links. Increment 1, whose IOT&E is scheduled to begin in FY00, consolidates DSP and Attack and Launch Early Reporting to Theater ground stations into a single CONUS ground station, and will operate with DSP satellite data. Increment 1a will incorporate the HEO sensor payloads and the associated modifications to the ground processing software. Increment 2 upgrades Increment 1 software and hardware with the functions necessary to operate with the new high-altitude SBIRS satellites, as well as residual DSP satellites. Increment 2 also includes the Multi-Mission Mobile Processors mobile terminals to fulfill the Army Joint Tactical Ground Station in-theater and SBIRS strategic processing requirements. Increment 3 will provide the functionality necessary to operate SBIRS Low satellites.

## **BACKGROUND INFORMATION**

SBIRS was initiated in 1995 as a replacement for the Follow-on Early Warning System acquisition, which was canceled due to cost and requirements problems. Since SBIRS satellites need to be deployed before the DSP system ends its useful life, they were placed on an accelerated schedule and selected as a lead program for acquisition reform. Much of the traditional program documentation was reduced or consolidated into a Single Acquisition Management Plan; emphasis was placed on direct involvement through Integrated Product Teams rather than traditional documentation reviews. The TEMP was maintained as a key document, and an initial TEMP was developed in 1995.

The SBIRS High component entered the EMD phase following a Milestone II DAB review in October 1996. This decision was supported by an operational assessment directed by DOT&E and conducted by AFOTEC. The operational assessments focused on four areas: major impacts affecting potential operational effectiveness and suitability; programmatic voids; program documentation and testability; and the ability of the program to support adequate operational test and evaluation. Issues raised through these operational assessments included the difficulty of testing for several ORD requirements, inadequacy of the Multi-Mission Mobile Processors test concept, increasing software development risk, a lack of realism in operational scenario development, and inadequacies in testbed fidelity. Issue resolution plans were put in place prior to the DAB and the TEMP was revised. DOT&E formally approved the revised TEMP in April 1998. SBIRS Low entered the Program Definition and Risk Reduction (PDRR) phase with Milestone I approval in August 1999. Two PDRR contracts were awarded.

The SBIRS test strategy is built around a combination of operational assessments, combined developmental/operational testing, and dedicated IOT&E. These operational test and evaluation events progress in a building-block manner beginning with analyses, modeling, and validated simulation, and

ending with hardware-in-the-loop testbeds and field tests on ground systems and on-orbit satellites. Modeling, simulation, and testbeds will be used to evaluate those areas in which field testing cannot be conducted, such as actual missile attacks and operation in nuclear environments. DOT&E is involved throughout the test program to provide operational perspectives and feedback from the early design phases through the final field tests.

## **TEST & EVALUATION ACTIVITY**

Based on a restructured FY00 budget, the Air Force made substantive programmatic changes to both the SBIRS High and SBIRS Low systems during FY99. For the SBIRS High system, the Air Force delayed launch of the first GEO satellites from FY02 to FY04. In March 1999, the Air Force formed a Joint Estimate Team to restructure the SBIRS High contract to accommodate the FY99 and FY00 budgets, and to revise the GEO satellite schedule and incremental deliveries of the ground segment in support of the delayed satellite schedule. DOT&E reviewed the Joint Estimate Team proposals and conferred with the Air Force on a SBIRS High re-baseline that incorporates an adequate test strategy described below.

For the SBIRS Low satellites, the Air Force delayed first launch from FY04-FY06. Furthermore, the Air Force cancelled two proof-of-concept demonstration satellites, the Flight Demonstration System and the Low Altitude Demonstration System, due to continuing cost overruns. The Program Definition and Risk Reduction phase of SBIRS Low was also restructured to focus on a more robust ground test program. DOT&E concurred with the changes made to the ground test program, but recommended alternative on-orbit risk reduction tests in place of the cancelled flight demonstrations. In July 1999, DOT&E recommended that the Department direct the Air Force to develop an acquisition strategy with significant design flexibility in the first six satellites, and a one year hiatus between launching those and the remaining satellites, as described further below. This strategy should provide an adequate understanding of the SBIRS Low satellites' performance prior to committing to a final satellite design or placing the majority of satellites in orbit.

Increment 1 IOT&E (DSP ground consolidation), originally due to begin in March 1999, was delayed until FY00 due to problems with ground software development and integration. IOC on the Increment 1 ground system was originally scheduled for February 2000, but is expected to be delayed by at least several months. The number and severity of software deficiencies found in development tests precluded AFOTEC and DOT&E from accepting the system for operational testing. These deficiencies involved mission software instability, communications availability, data throughput limitations, and tracking, telemetry, and control problems.

SBIRS High activity involved ground testing of engineering test models of the infrared starrer and scanner sensors. These tests were conducted at the contractor's Sensor Test Integration Laboratory (STIL) cryo-vacuum chambers between November 1998 and March 1999. The STIL is a Hardware-in-the-Loop cryo-vacuum testbed located at Northrop Grumman in Bethpage, NY, used to measure and characterize the performance of the SBIRS sensors. Data from STIL tests is being used for sensor design validation and to support validation, verification, and accreditation of end-to-end simulations and models.

Data from early portions of these tests were degraded due to an out-of-focus condition on the starrer sensor, and outgassing of water-ice from paint inside the telescope assembly in the cryo-vacuum conditions simulating space conditions. Some tests were re-run, and the schedule was adjusted to prioritize the remaining tests within the remaining test time. Data from the starrer tests indicated that most design specifications were met or exceeded by substantial margins. However, for the scanner,

several anomalies were noted such as periodic noise in focal plane array outputs, lower than expected background levels, and scanner velocity errors. Implications of these anomalies to the HEO flight design will have to be determined before the HEO payload critical design review scheduled for 3QFY00. Furthermore, there were uncertainties in the test results due to lack of National Institute of Standards (NIST)-traceable calibration of the chamber or its optical scene generator. Changes to the sensor design to correct deficiencies, particularly outgassing, will need to be tested and verified during qualification tests on production-representative sensors. A new cryo-vacuum chamber facility is being developed for this purpose at Aerojet in Azusa, CA, which will be calibrated to NIST standards.

For SBIRS Low, DOT&E requested that the Air Force incorporate on-orbit tests to replace the cancelled Flight Demonstration System and Low Altitude Demonstration System flight demonstrations. As a result, the System Program Office modified their acquisition strategy to include a flexible design approach that permits early on-orbit experimentation and tests on the first six satellites prior to finalizing the production design. The Air Force scheduled a one-year launch hiatus to allow for test and evaluation of the first six satellites prior to subsequent launches. This approach will allow developers and users to explore the operational environment, gain early on-orbit experience, and evaluate the effectiveness and suitability of the system prior to deploying the full constellation. Test and experimentation may include alternative approaches to mission management and autonomous satellite operations, communications network routing, cross-linking capability, sensor designs, characteristics, and integration including tracking, surveillance-to-track handover, and discrimination capabilities and algorithms. The launch hiatus, combined with the flexible design approach recommended by DOT&E, will allow developers to explore alternatives to software and on-orbit computational architecture and capability, and vehicle life monitoring including effects on electronics, cryo-cooling systems, lubricants, coatings, etc.

DOT&E will make a final evaluation of SBIRS operational effectiveness and suitability (on the basis of IOT&E results) when each of the three major increments are fielded, including both fixed and mobile assets.

## **TEST & EVALUATION ASSESSMENT**

Increment 1 IOT&E, due to begin in March 1999, was delayed to FY00 due to unforeseen problems with hardware and software. Hardware problems primarily involved inadequate processor sizing and lack of reliability in, and delays in delivery of government-furnished communications, resulting in less than required system availability. Communication problems have been largely resolved, but as of the end of FY99 serious problems remained with software stability and maturity. Software instability mainly involves the tracking, telemetry, and control functions. The high concurrency between development of new software and the correction of deficiencies in previous software resulted in configuration management problems and a compressed schedule that could not be executed. The number and severity of uncorrected software deficiencies has precluded AFOTEC and DOT&E from accepting the system for IOT&E. We expect SBIRS Increment 1 to breach the approved program baseline date of February 28, 2000 for Increment 1 operations by several months.

The SBIRS High test strategy, discussed at length below, will be adequate to support evaluation of operational effectiveness and suitability at critical decision points in the program if the testing program is as robust as described. We are working with the SBIRS High program to achieve this outcome. Programs like SBIRS High that have a small number of satellites normally do not have the traditional production decision based on completed operational testing of a production system. Rather, a decision to produce the system is made early in the program based upon a favorable assessment of the initial satellite design and review of the acquisition and test strategies. However, the SBIRS High

program does incorporate a series of test activities which support intermediate design and production decision points throughout the acquisition process (e.g. part/component design, build, and test; subassembly integration and test; subsystem integration and test; space vehicle integration and test.) There is adequate testing to support the decision points to enter subsequent production phases, assuming that the program incorporates the necessary test assets, with the required quality, as described below.

Specifically, the SBIRS High acquisition strategy allows for adequate testing on the first HEO and GEO sensor payloads to support a production decision, as early as 4QFY03, on the GEO 3 through GEO 5 sensor payloads (HEO has no production beyond the first two RDT&E-funded payloads). Two types of information are needed to support this decision. First is a demonstration that the sensor payloads meet functional and environmental specifications. Functional specifications relate to electrical and mechanical performance of the payload subsystems and their interfaces, and environmental specifications relate to thermal, vibration, and other loads expected in the transportation, launch, and space environments. The second type of information needed is a prediction, based on test data, that the sensor payload will provide the quantity and quality of data needed for the system to support the system's operational requirements (e.g., probability of warning, launch point accuracy).

Data to provide this information will come from a combination of previous pathfinder tests on early engineering models of the sensors, planned qualification and acceptance tests on production-representative HEO and GEO sensor payloads and their subsystems, and validated modeling and simulation. Pathfinder tests demonstrated encouraging results, and identified some design flaws to be corrected in the flight design. One of the most critical findings was a sensitivity degradation from water-ice condensation on the sensor optics, caused by outgassing from the telescope's paint at the vacuum and thermal conditions to be expected in space. As part of the sensor qualification tests, a specific demonstration of a solution to the water-ice condensation problem must be provided. The solution must include both pre-launch contamination control procedures and an on-orbit remediation capability.

The pathfinder tests were conducted at the Northrop-Grumman Sensor Test and Integration Laboratory (STIL) cryo-vacuum facility in Bethpage, New York. Qualification and acceptance tests will be conducted at the Advanced Sensor Test Facility (ASTF), which is a new cryo-vacuum chamber test facility being developed at Aerojet in Azusa, California. Data from STIL tests are being used to improve the production design, to assist in validation of models and simulations, and to optimize the design of the new chambers.

While STIL pathfinder tests were necessary and highly informative, they were intended to be early tests of non-production-representative systems rather than to qualify flight systems. Because of this, there were significant differences between the engineering sensor model used in the STIL and a realistic flight design, including the lack of a gimbal, lack of a star tracker, and some subsystems (power, signal processing) located outside the chamber. Furthermore, the contractor decided to change sensor chip vendors for the starer sensor following STIL testing. Combined with uncertainties in STIL calibration and test anomalies, these factors suggest that it would be prudent to conduct further scene projection tests, as described below, on flight-representative sensors at Azusa.

The sequence of tests described above (pathfinder, sensor payload qualification, and simulation) will address and reduce risk in the highest three of five risk areas: payload focal plane performance; the telescope's gimbal and pointing control assembly; and performance of on-board signal processing, detection, and tracking algorithms. These tests will also partially address risk in a fourth area, software development and integration, as it relates to embedded sensor management and processing software. The fifth risk area to be addressed is space vehicle integration.

Integration of the sensor payload into the space vehicle begins following sensor payload qualification/acceptance testing. The GEO space vehicle includes the spacecraft structural bus and sensor payload, along with its critical subsystems: propulsion; communications; command and data handling; electrical power; guidance, navigation, and control; and flight software. Two types of information are needed on the first integrated GEO satellite to support a production decision on integration of GEO 3 through GEO 5. First is a demonstration that the integrated space vehicle meets functional and environmental specifications. Second is a demonstration that the integrated space vehicle correctly interfaces with the ground segment. The acquisition strategy allows for adequate testing to provide this information, all of which is expected to be available as early as 3QFY04.

Data to provide this information will come from functional and qualification/ acceptance tests on the integrated GEO space vehicle and its components, and from ground/space intersegment functional tests. These qualification/acceptance tests will be conducted at the Lockheed-Martin cryo-vacuum facilities in Sunnyvale, California. HEO integration will be accomplished by the host contractor. The intersegment functional tests include verification of satellite Tracking, Telemetry, and Control (TT&C) processes and interfaces, and payload data validity. These tests will be conducted by linking the developmental or fielded ground segment (e.g., the Mission Control Station) with the satellite vehicle at the factory, as part of a SBIRS System Testbed.

The final ground test event prior to launch of the first GEO is testing of a ground segment capable of interoperating correctly with SBIRS High satellites. This fielding and testing are scheduled for 2QFY03. Although the ground segment is one-of-a-kind, and there is no further production decision, successful fielding and testing of the ground segment will increase our pre-launch confidence that the SBIRS ground/space system-of-systems would meet operational requirements. This test will address and reduce the significant risk in ground-based software development and integration, as well as reduce risk in ground-based detection and tracking algorithm performance. This ground segment test will also support initial evaluation of operational suitability requirements related to Reliability, Availability, and Maintainability (RAM).

High quality test assets are needed to support the tests described above. Test assets needed are well-designed cryo-vacuum chambers for sensor payload and space vehicle qualification testing, and an end-to-end, hardware-in-the-loop, SBIRS System Testbed to support integrated ground/space segment testing. The cryo-vacuum chamber and the SBIRS System Testbed must provide as much operational realism as possible, and supporting models and simulations must be validated against flight and test data. The cryo-vacuum chamber at the Sunnyvale location has been used in previous space acquisitions (e.g., MILSTAR), meets MIL-STD-1540C/D standards, and is of sufficient quality for SBIRS qualification and acceptance tests. The cryo-vacuum facilities at Asuza, however, are still being constructed and require additional capability beyond MIL-STD-1540C/D. This additional capability, needed to provide operational realism to sensor tests, is an ability to project infrared scenes similar to what was used in the STIL. As with the STIL, realistically simulated missile flight kinematics, time-varying plume brightness, and earth background clutter levels and characteristics (e.g., terrain, time of year, viewing angle) must be validated against relevant flight data (e.g., DSP, MSTI) and must conform to intelligence-validated estimates. In addition, the cryo-vacuum chamber thermal environment and scene generator must be calibrated to National Institute of Standards and Technology (NIST)- standards. Extension and scaling of performance results from the cryo-vacuum chamber's physical and geometric limits (e.g., number of targets, field of view) to an entire satellite or constellation can be done through the SBIRS System Testbed and its supporting models and simulations.

For the SBIRS System Testbed, sufficient realism can be obtained by providing real-time communication interfaces between the SBIRS System Testbed's digital simulations and the hardware

element under test (e.g., the sensor payload, the integrated space vehicle, or the ground segment). Furthermore, the SBIRS System Testbed should incorporate production-representative detection and tracking algorithms and mission software. Finally, models and simulations for the SBIRS System Testbed must undergo rigorous validation, as well as independent accreditation by AFOTEC as the operational test agency. It is possible that a HEO payload will be on orbit by the time that the SBIRS System Testbed is needed. If so, real-world HEO data should be used to further validate the SBIRS System Testbed.

The SBIRS High test strategy must continue beyond the test events discussed above, to include both ground and on-orbit tests. These tests will support the users' operational acceptance of the fielded system, and system certification and interoperability standards. The final DOT&E evaluation will be made in FY06, when end-to-end field tests with two HEO and two GEO satellites, integrated with the ground system, will have been completed. Deficiencies found during operational tests will be reported to acquisition executives and referred to the developer and users for correction.

The SBIRS Low satellites and Increment 3 Ground Segment will require a phased test program similar to that of SBIRS High. In addition, SBIRS Low development and test programs will face significant additional technical challenges and risk in the following areas:

- Flight and ground software to manage autonomous operation of multiple satellites and multiple sensors.
- Timely and accurate handover from the wide field-of-view surveillance sensor to the narrow field-of-view tracking sensors on the same satellite.
- Timely and accurate handover of tracking state vectors from one satellite to another satellite.
- On-orbit data fusion from multiple sensors to provide stereo tracking.
- Mid-course discrimination of Re-entry Vehicle from other objects.
- Operation in the high radiation environment of the Van Allen belts.

The test program to support the recently restructured SBIRS Low program is still under development.

## **LESSONS LEARNED**

SBIRS Increment 1 delays demonstrate that software development and integration remain a difficult and challenging aspect for space and C<sup>3</sup> programs, even when much of the code is reused from previous programs.

Adjustments made to the SBIRS High and Low acquisition strategies demonstrate that early involvement by DOT&E in space programs is critical to minimize the risk of entering IOT&E with an inadequate system. Due to the long lead time needed to acquire satellite systems, and the few items acquired, reliable assessments to support Milestone II major decisions require an extensive understanding of the system, which can only be gained from early involvement.

## **RECOMMENDATIONS**

The SBIRS High program office must ensure the test program is fully planned, funded, and executed to support the decision points built into the acquisition strategy.

For Increment 1, more realistic software development schedules and better configuration management practices must be followed to avoid high concurrency between developing new software versions and correcting deficiencies from previous versions.

For SBIRS High ground tests, qualification and acceptance cryo-vacuum chambers must be calibrated to NIST standards, and dynamic earth background phenomena relevant to missile detection and tracking must be incorporated into sensor performance tests, either through hardware or at the signal processing stage.

For SBIRS High satellites, it is essential that a suitable telescope optical chamber paint be used, and that the right purging procedures be implemented and re-tested prior to launch, to prevent on-orbit water-ice outgassing onto the focal plane.

For SBIRS Low satellites, full production should not proceed unless and until there is a well-defined flexible design and on-orbit test strategy in place to address these technical risks and assess design alternatives from the first few satellites.